Research Article

Successional and Transitional Models of Natural South Florida, USA, Plant Communities

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ABSTRACT

We developed a conceptual successional model for South Florida that describes relationships among major natural plant communities in terms of the region's two major environmental processes, hydrology and fire regime. We next developed several conceptual transitional models that provide more detail on the characteristics of fire regimes that determine successional and disturbance transitions between communities. Transitions between communities in the models were based largely upon personal field experience, aerial photography, and limited data, such as tree ages and organic soil ^{14}C dates. We used our best professional judgment to fill information gaps. Major assumptions in the models were the ready availability of seeds, a long-term perspective for development of communities, and differences in rates of change across a transition depending on direction of change. The models will assist land managers to understand long-term implications of their management decisions.

Keywords: ecosystem models, fire, hydrology, organic soils, plant communities, South Florida

Citation: Duever, M.J., and R. Roberts. 2013. Successional and transitional models for restoration and management of natural South Florida, USA, plant communities. Fire Ecology 9(1): 110-123. doi: 10.4996/fireecology.0901110

INTRODUCTION

An understanding of a natural ecosystem's major characteristics and how they relate to the dominant processes that have shaped these characteristics is crucial for the appropriate long-term management of any ecosystem and, as necessary, its successful restoration. While we may have a great deal of information about many types of ecosystems and how each works, every site on a landscape has a unique setting and has been affected by a unique set of historic influences. Models represent a useful approach to organizing available information on a site's ecosystems in terms of their major components, such as plant communities, and how they are affected by natural processes, such as hydrologic and fire regimes.

The purpose of this paper is to describe several models that we have developed for South Florida to assist in the synthesis of available information on the region's plant communities and the dominant processes that have shaped their characteristics and distribution in the region. We have also described the information sources and assumptions upon which the models were based. A particularly important part of this effort was to capture the extensive experience of land managers who have for decades been observing the effects on lands that they have been managing from a wide variety of natural environmental events and land management activities, both on their own and nearby properties. This information can now be made available to future land managers to expedite their ability to effectively manage these lands and to educate the general public about the management needs of these sites.

METHODS

Site Description

South Florida was originally a wetland ecosystem bordered on the east and west coasts by relatively narrow strips of upland communities. The freshwater Everglades marshes occupied much of the eastern half of the peninsula south of Lake Okeechobee. The southwestern portion of the area was occupied by the Big Cypress Swamp, which was dominated by forested wetlands with some extensive herbaceous wetlands and islands of upland forest. The lands north of the Big Cypress Swamp and the east and west coastal uplands were dominated by upland pine forests with imbedded small to large forested and herbaceous wetlands. With the exception of the Caloosahatchee River and Lake Okeechobee, there were few freshwater open bodies of water in South Florida. The majority of the saline coastal communities with emergent vegetation were located on very gentle topographic gradients along the southern tip of the Florida peninsula. They were predominantly mangrove (*Rhizophora-Laguncularia-Avicennia-Conocarpus*) forests, with brackish marshes located between the inland freshwater communities and the mangrove forests.

During pre-development, the gentle slopes and heavy summer rains resulted in an accumulation of surface water across much of the South Florida landscape. When water levels reached a sufficient height, this mass moved as a shallow sheet of water towards the coasts. The combination of the depth and duration of this flooding was one of the primary determinants of the types of plant communities that developed on the South Florida landscape (Craighead 1971, Duever 1984, Gunderson 1994, McVoy *et al.* 2011). The other major determinant was the fire regime. Given the long dry season in South Florida, particularly during the hot late spring months at the end of the dry season, most of South Florida can be vulnerable to fires. Thus, all South Florida plant communities can also be considered a product of their fire regime (Wade *et al.* 1980). Most upland communities burn frequently, with fire frequency and severity decreasing down the moisture gradient to the lowest and wettest communities. However, some upland communities burn relatively infrequently because of their location within or adjacent to deep wetlands. At the other extreme, while vegetation in ponds may be very unlikely to burn, some of these ponds are the product of rare organic soil fires that created their deep depressions.

Most of the original South Florida landscape and its associated plant communities have been drastically altered in their character and distribution by human activities (Davis and Ogden 1994). However, there are still some extensive landscapes, particularly in Everglades National Park and Big Cypress National Preserve, as well as a number on smaller protected areas scattered across South Florida that remain in a relatively natural condition. It is with these sites in mind that we have tried to pull together available information on the management and restoration of natural plant communities to maximize the possibility of their survival in the rapidly developing South Florida landscape.

Model Development

The development of the South Florida conceptual succession and transition models was facilitated by the creation of an *ad hoc* committee of the South Florida Interagency Fire Management Council (SFIFMC). The goal of the committee was to develop a plan that would create mechanisms for the appropriate application and control of fire in natural ecosystems of the Greater Everglades by 2050. The work of the SFIFMC *ad hoc* committee occurred at meetings held periodically over six years, from 2001 through 2006, and involved a large number of representatives from various federal, state, and local governmental agencies as well as from several private groups.

The first step in developing the conceptual succession and transition models was to arrive at a consensus for geographic boundaries and the major South Florida plant community types that were appropriate to include in the models. We have defined South Florida as including roughly those lands in peninsular Florida south of a line from Fort Myers on the Gulf of Mexico through Lake Okeechobee to Stuart on the Atlantic Ocean. Numerous Florida plant community classifications have been developed over the years for a variety of purposes (Harshberger 1914, Harper 1927, McPherson 1973, Alexander and Crook 1974, Florida Natural Areas Inventory and Florida Department of Natural Resources 1990). It was intended that this current classification be compatible with the work of others, while selecting a suite of community types that met the criteria appropriate to our objectives. Two primary criteria were used: (1) that it be a naturally occurring community, and (2) that it could be explicitly related to the dominant environmental processes and influences, particularly fire, hydrology, and to a lesser extent, soil characteristics.

The current models were formed by adapting conceptual ecosystem models created for similar systems in the South Florida watershed Corkscrew Swamp (Duever *et al.* 1976), Big Cypress Swamp (Duever 1984), Kissimmee River floodplain (Duever 1993), Avon Park Air Force Range (The Nature Conservancy 1995) and Disney Wilderness Preserve (DWP; The Nature Conservancy 1997). Also, the DWP model was the latest iteration of these models, and was one of the first to include upland communities as well as to identify fire regimes that would maintain a community type or allow it to transition to an earlier or later successional stage.

While many transitions in the earlier models were based on a variety of sources, such as field experience at many sites, current and past aerial photography, photographs taken at different times at the same site, tree ages from annual ring counts, and ^{14}C dates, some transitions were based on our best professional judgment of individuals who had been working in these ecosystems for many years. Since there is currently little site-specific data for many South Florida plant communities, we used or adjusted the transitions established for the previously modeled sites as appropriate based on our knowledge and experience in South Florida.

RESULTS

Plant Communities

We identified 21 major plant community types in South Florida that met the criteria for inclusion in our models. Characteristics of each of these are given in Table 1 according to its topographic setting and soils, dominant vegetation, hydrology, and fire regime.

The upland communities in much of South Florida are primarily restricted to small to large islands in the interior of the peninsula or to belts that become narrower and more fragmented from north to south along the east and west coasts. They are more extensive north of Big Cypress Swamp in southwest Florida. Originally, the high wet season water table and frequent dry season fires maintained an open

Table 1. Dominant biological components and environmental characteristics of plant communities in South Florida. Common and Latin names follow Wunderlin and Hansen (2011).

Plant Community	Topographic setting and soils	Dominant vegetation *	Hydrology	Fire
Lake, Pond	Basins of standing water that are too deep for emergent vegetation.	Aquatic plants: floating or submerged.	Normally have water above ground. Edges or all (depending on size and depth) could dry down in extreme (>50 yr) droughts.	During extreme droughts, exposed dry organics on bottom can burn. Can be created by organic soil fires.
Stream	Flowing water in a distinct channel that is too deep for emergent vegetation.	Aquatic plants: floating or submerged.	Normally continuous flows, with amounts and rates of flow dependent on size of pulses of water from rainstorms or water control structure releases. Groundwater baseflow inputs.	During extreme droughts, exposed dry organics on bottom of old oxbows can burn.
Floodplain Swamp	Lands associated with streams that are regularly, but not continuously, inundated by flowing water.	Canopy of bald-cypress and mixed hardwoods, (e.g., Carolina ash, red maple, pond apple, cabbage palmetto, American elm).	Shallow to deep intermittent flooding, depending on size of pulses of water from rainstorms or water control structure releases. Groundwater baseflow inputs.	Fire about every 20 yr to 50 yr promotes cypress along swamp edge. Less frequent fire (±100 years) promotes hardwoods in swamp interior.
Mixed Cypress –Hardwood Swamp	Wetlands with deep (>0.3 m) organic soils.	Closed canopy of bald-cypress and mixed hardwoods, (e.g., red maple, sweetbay, Carolina ash, Carolina willow, pond apple, and dahoon holly with occasional cabbage palmetto).	Inundated 8 mo yr^{1} to 10 mo yr^{1}. Normal wet season water depths of 0.5 m to 0.6 m. Annual water table fluctuation of 0.6 m to 1.2 m.	Found on sites infrequently (±100 years) reached by fire, due to extended inundation and high soil moisture.
Cypress	Wetlands with sandy or shallow (<0.3 m) organic soils.	Canopy dominated by small- to medium-sized bald-cypress.	Inundated 6 mo yr^{1} to 8 mo yr^{1} Normal wet season water depths of 0.3 m to 0.5 m. Annual water table fluctuation of 0.9 m to 1.5 m.	Maintained by light to moderate intensity surface fires every 20 yr to 60 yr.
Mangrove Swamp	Tidal sites with sand, rock, or organic substrates.	Canopy dominated by red, black, or white mangroves; or buttonwood.	Daily tidal inundation. Water fresh to hypersaline.	Developed and maintained by the absence of fire.
Organic Soil Shrub Wetland	Wetlands, sheet-flow sloughs, and edges of lakes and streams with organic soils.	Single or mixed species, open to dense thickets of Carolina willow or buttonbush.	Inundated 6 mo yr^{1} to 10 mo yr^{1}. Normal wet season water depths of 0.15 m to 0.6 m. Annual water table fluctuation of 0.5 m to 0.9 m.	Maintained by low intensity surface fires every 18 yr to 30 yr.
Freshwater Marsh	Depression and flow-way wetlands, and fringes of lakes and streams on organic soils.	Tall (1.5 m to 3 m), dense herbaceous community, often only a few species, e.g. pickerelweed, bulltongue arrowhead, Jamaica swamp sawgrass, maidencane, fireflag.	Inundated 6 mo yr^{1} to 10 mo yr^{1}. Normal wet season water depths of 0.3 m to 0.6 m. Annual water table fluctuation of 0.6 m to 0.9 m.	Maintained by moderately intense fires about every 1 yr to 10 yr.
Mineral Soil Shrub Wetland	Depression and flow-way wetlands, and fringes of lakes and streams on mineral soils.	Single or mixed species, open to dense thickets of wax myrtle, groundsel tree, and gallberry.	Inundated 2 mo yr^{1} to 6 mo yr^{1}. Normal wet season water depths of 0.15 m to 0.4 m. Annual water table fluctuation of 0.9 m to 1.2 m.	Maintained by low intensity fires about every 9 yr to 15 yr.
Dwarf Cypress	Depression and flow-way wetlands, and fringes of lakes and streams on limestone bedrock.	Single species, open stands of stunted bald-cypress with sparse groundcover.	Inundated 2 mo yr^{1} to 6 mo yr^{1}. Normal wet season water depths of 0.15 to 0.4 m. Annual water table fluctuation of 0.9 m to 1.2 m.	Maintained by low intensity fires about every 10 yr to 20 yr.
Wet Prairie	Depression and flow-way wetlands, and fringes of lakes and streams on mineral soils.	Short (0.5 m to 1.3 m), open, diverse herbaceous community with many species of grasses, sedges, and forbs, (e.g., sand cordgrass, beaksedges, milkworts, St. John's-wort, hairawn muhly, Jamaica swamp sawgrass).	Inundated 2 mo yr^{1} to 6 mo yr^{1}. Normal wet season water depths of 0.15 m to 0.4 m Annual water table fluctuation of 0.9 m to 1.2 m	Maintained by moderate to high intensity fires about every 1 yr to 5 yr.

* See page 115 for Latin names for plants.

Table 1, continued. Dominant biological components and environmental characteristics of plant communities in South Florida. Common and Latin names follow Wunderlin and Hansen (2011).

Plant community	Topographic setting and soils	Dominant vegetation *	Hydrology	Fire
Coastal Marsh	Coastal saline sites with sand, shell, rock or organic substrates.	Short <1.3 m), open, diverse herbaceous community with many species of grasses, sedges, and forbs (e.g., smooth cordgrass, black rush, spikerush).	Daily tidal inundation. Water fresh to hypersaline. Freshwater sheet flow during wet season.	Maintained by moderate to high intensity fires about every 1 yr to 5 yr.
Hydric Pine Flatwoods	Light to dark brown, sandy soils on sites with little topographic relief.	Canopy trees primarily slash pine. Diverse, primarily herbaceous groundcover with about 500 species (e.g., wiregrass, bluestems, saw palmetto).	Inundated 1 mo yr^{-1} to 2 mo yr^{-1}. Normal wet season water depths from 0 m to 0.15 m above ground. Annual water table fluctuation of 0.9 m to 1.2 m.	Maintained by moderately intense fires about every 1 yr to 6 yr.
Hydric Pine Flatwoods Shrubby	Light to dark brown, sandy soils on sites with little topographic relief.	Canopy trees primarily slash pine. Understory dominated by open to dense thickets of shrubs, particularly wax myrtle.	Inundated 1 mo yr^{-1} to 2 mo yr^{-1}. Normal wet season water depths from 0 m to 0.15 m above ground. Annual water table fluctuation of 0.9 m to 1.2 m.	Maintained by low to moderate intensity fires about every 8 yr to 15 yr.
Mesic Pine Flatwoods	Light to dark brown, sandy soils or limerock on sites with little topographic relief.	Canopy trees primarily slash pine. Understory dominated by dense saw palmetto.	Inundated 0 mo yr^{-1} to 1 mo yr^{-1}. Normal wet season water depths from 0 m to 0.9 m below ground. Annual water table fluctuation of 0.9 m to 1.2 m.	Maintained by moderately intense fires about every 1 yr to 6 yr.
Mesic Pine Flatwoods, Shrubby	Light to dark brown, sandy soils on sites with little topographic relief.	Canopy trees primarily slash pine. Understory dominated by open to dense thickets of shrubs, particularly gallberry, coastalplain staggerbush, wax myrtle, blueberry, and saw palmetto.	Inundated 0 mo yr^{-1} to 1 mo yr^{-1}. Normal wet season water depths from 0 m to 0.9 m below ground. Annual water table fluctuation of 0.9 m to 1.2 m.	Maintained by low to moderate intensity fires about every 8 yr to 15 yr.
Hydric Hammock	Loamy or sandy soils on elevated sites often within or adjacent to larger wetlands	Forest with a closed canopy that includes a variety of tree species (e.g., laurel oak, cabbage palmetto, red maple, swamp bay). Groundcover is sparse.	Inundated 1 mo yr^{-1} to 2 mo yr^{-1}. Normal wet season water depths from 0 m to 0.15 m above ground. Annual water table fluctuation of 0.9 m to 1.2 m.	Found on sites that have not experienced fire for more than 100 yr.
Mesic Hammock	Sand, shell, or rock substrates on elevated sites often within or adjacent to larger inland or coastal wetlands	Closed canopy of Virginia live oak and tropical hardwoods. Groundcover is sparse.	Inundated 0 mo yr^{-1} to 1 mo yr^{-1}. Normal wet season water depths from 0 m to 0.9 m below ground. Annual water table fluctuation of 0.9 m to 1.2 m.	Found on sites that have not experienced fire for more than 100 yr.
Coastal Strand	Well-drained sands on beach ridges adjacent to high-energy beaches.	Dense thickets of salt tolerant shrubs, vines, and small trees, including saw palmetto, seagrape, myrtle oak, Virginia live oak, sand live oak, buttonsage, greenbrier, and cabbage palmetto.	Wet season water table usually more than 0.9 m below ground.	Maintained by low to moderate intensity fires about every 2 yr to 15 yr.
Scrub	White well-drained sands on locally higher elevations or at the top of steep slopes.	Dense thickets of low (<3.0 m) shrubs and xeric oaks, including myrtle oak, live oak, sand live oak, with scattered patches of mostly bare white sand and a very scattered overstory of slash pine.	Wet season water table usually more than 0.9 m below ground.	Maintained by high intensity fires every 6 yr to 55 yr.
Xeric Hammock	White well-drained sands on locally higher elevations or at the top of steep slopes.	Dense, tall (3.0 m to 6.0 m) closed canopy forest of xeric oaks, including myrtle oak, Virginia live oak, sand live oak, with a very scattered overstory of slash pine or sand pine and little ground cover.	Wet season water table usually more than 0.9 m below ground.	Develops in the absence of fire for 50 yr.

* See page 115 for Latin names for plants.

Table 1, continued. Dominant biological components and environmental characteristics of plant communities in South Florida. Common and Latin names follow Wunderlin and Hansen (2011).

* Scientific names for plants listed as dominant vegetation, in alphabetical order by common name:
American elm = *Ulmus americana* L.
bald-cypress = *Taxodium distichum* (L.) Rich.
bulltongue arrowhead = *Sagittaria lancifolia* L.
beaksedges = *Rhynchospora* spp.
black mangrove = *Avicennia germinans* (L.) L.
black rush = *Juncus roemerianus* Scheele
blueberry = *Vaccinium* spp.
bluestems = *Andropogon* spp.
buttonbush = *Cephalanthus occidentalis* L.
buttonsage = *Lantana involucrata* L.
buttonwood = *Conocarpus erectus* L.
cabbage palmetto = *Sabal palmetto* (Walter) Ladd. ex Schult. & Schult. f.
Carolina ash = *Fraxinus caroliniana* Mill.
Carolina willow = *Salix caroliniana* Michx.
coastalplain staggerbush = *Lyonia fruticosa* (Michx.) G.S. Torr.
dahoon holly = *Ilex cassine* L.
fireflag = *Thalia geniculata* L.
gallberry = *Ilex glabra* (L.) A. Gray
greenbrier = *Smilax* spp.
groundsel tree = *Baccharis halimifolia* L.
hairawn muhly = *Muhlenbergia capillaris* (Lam.) Trin.
Jamaica swamp sawgrass = *Cladium jamaicense* Crantz
laurel oak = *Quercus laurifolia* Michx.
maidencane = *Panicum hemitomon* Schult.
milkworts = *Polygala* spp.
myrtle oak = *Quercus myrtifolia* Willd.
pickerelweed = *Pontederia cordata* L.
pond apple = *Annona glabra* L.
red mangrove = *Rhizophora mangle* L.
red maple = *Acer rubrum* L.
sand cordgrass = *Spartina bakeri* Merr.
sand live oak = *Quercus geminata* Small
sand pine = *Pinus clausa* (Chapm. ex Engelm.) Vasey ex Sarg.
saw palmetto = *Serenoa repens* (W. Bartram) Small
seagrape = *Coccoloba uvifera* (L.) L.
smooth cordgrass = *Spartina alterniflora* Loisel.
spikerush = *Eleocharis* spp.
St. John's-wort = *Hypericum* spp.
swamp bay = *Persea palustris* (Raf.) Sarg.
sweetbay = *Magnolia virginiana* L.
Virginia live oak = *Quercus virginiana* Mill.
wax myrtle = *Myrica cerifera* (L.) Small
white mangrove = *Laguncularia racemosa* (L.) C.F. Gaertn.
wiregrass = *Aristida stricta* Michx.

canopy of slash pine (*Pinus elliotii* var. *densa* Little & K.W. Dorman) with a dense and very diverse groundcover of herbaceous vegetation and low shrubs on most upland sites (Table 1). With a reduced fire frequency, larger shrubs and trees gradually invade and over time can establish a mixed hardwood forest community with a much reduced groundcover. The low fire frequency hardwood forests or hardwood hammocks were typically restricted to small, elevated islands within or adjacent to larger wetlands, with temperate plant species dominating on the more inland sites, and tropical species dominating on coastal sites that are more protected from winter cold fronts by the adjacent relatively warm ocean waters. The pine flatwoods and hardwood hammocks range across the hydrologic gradient from hydric forests on shallowly inundated sites during the wet season to mesic forests that have water at or above the ground surface for only short periods during the year. On the driest sites, there is often a low scrub oak community, which in the absence of fire will succeed to an oak hammock community dominated by Virginia live oak (*Quercus virginiana* Mill.) and a much reduced groundcover. Substrates are typically shallow to deep sands or bare limestone.

Herbaceous wetlands vary greatly in size, from small, shallow depressions on the order of only 10 m across up to the Everglades marshes that include millions of hectares. We divided them into two major types based on mineral versus organic soil type (Table 1). Mineral soil wet prairies can be found on shallow to deep sands, marl substrates, and level to very eroded limestone. They occur on shallower sites or the fringes of deeper herbaceous sites, and are typically very diverse plant communities. Structurally, the vegetation is relatively short and open, so that sunlight reaches the water surface over most of the wetland. Where the limestone is at or near the ground surface, light reaching the water surface can result in the development of a substantial algal periphyton community growing on the many surfaces present in the shallow water, including live plant stems, litter, logs, and the ground surface. Mineral soil wet prairies typically have shorter hydroperiods, are more shallowly inundated during the wet season, and have a greater annual water table fluctuation than do the organic soil marshes.

Organic soil marshes are found on shallow to deep mucky organic substrates. They support a less diverse community, but are more structurally developed. The vegetation is normally taller and often much denser than in wet prairies, so that little sunlight gets to the water surface, and there is little periphyton. They have longer hydroperiods, are more deeply inundated during the wet season, and do not have as great an annual water table fluctuation. In the absence of fires, woody shrubs and eventually trees invade both wet prairies and marshes. The shade produced by the new forest canopy typically results in a reduced cover of herbaceous vegetation with a very different shade-tolerant species composition.

Forested wetlands are dominated by cypress or mixed hardwoods or a combination of cypress and hardwoods. Cypress forests (*Taxodium distichum* [L.] Rich.) are more or less monospecific stands of cypress that occur on sites, such as topographic depressions, with shorter hydroperiods, relatively greater annual water table fluctuations, and a greater frequency of fires (Table 1). Mixed hardwood swamps dominate on sites that burn infrequently, such as in the center of larger wetlands or stream floodplains. These forested wetlands typically have longer hydroperiods and less water table fluctuation compared to cypress forests. Stream floodplains have a very erratic pattern of flooding with a wide range of annual water level fluctuation that is associated with small to large rainfall events in their watersheds. Forested wetlands can occur in a variety of sizes, such as small or large depressional wetlands, or narrow to broad fringing wetlands along lakes and streams. They can occur on a wide variety of substrates. More structurally developed and diverse communities tend to occur on organic substrates, and more stunted and less diverse communities on marl or limestone substrates.

Saline environments along the South Florida coasts are dominated by either mangrove forests or marshes (Table 1). They are most extensive in the Ten Thousand Islands along the southern tip of the Florida peninsula where they occupy very gentle slopes on marl or organic substrates. The coastal marshes are found primarily in the brackish ecotones between freshwater and saltwater ecosystems. Mangroves are present but less extensive in estuaries along the east and west coasts where the topographic gradients between the adjacent uplands and open waters of the estuaries are steeper. Along high energy sections of the coast, coastal strands supporting salt tolerant herbaceous and low woody vegetation are found behind the sandy beaches.

The deepest water sites are ponds, lakes, and streams (Table 1). These are permanently inundated, although shallows along their shorelines may be exposed during dry periods. They do not support vegetation that would burn, even when dry. However, some of the ponds are the result of organic soil fires that have created their depressions. Substrates are generally sand or rock, with varying amounts of organic accumulation.

Successional Model

The South Florida successional model distributed the plant communities in terms of their hydrologic and fire regimes (Figure 1). Upland communities, those without standing water above ground during most years, were distributed based on depth below the ground surface to the normal wet season water table. Wetland communities, those with standing water above ground for at least short periods during most years, were distributed on the basis of hydroperiod, which is the average annual number of days when the water table is at or

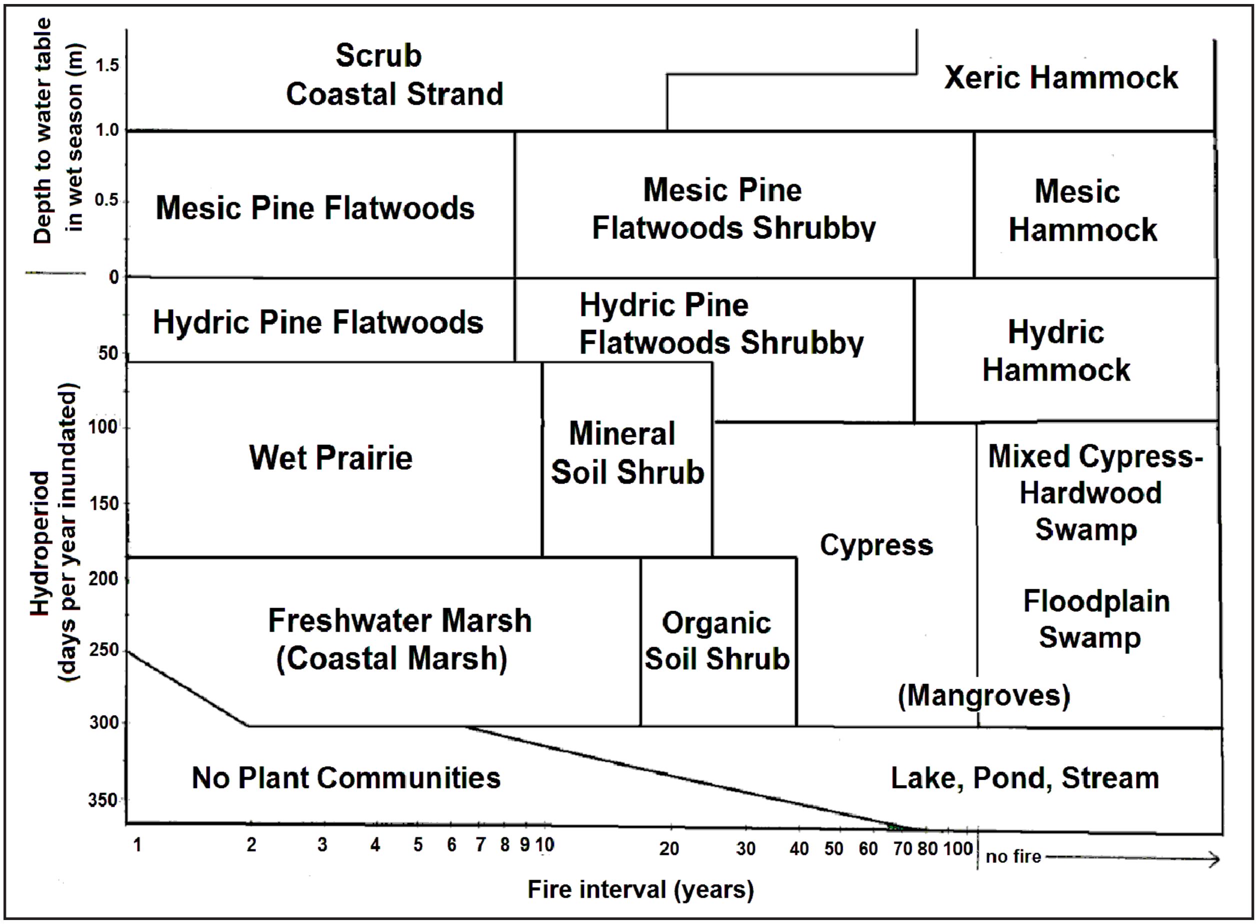

Figure 1. A conceptual successional model of the major South Florida plant communities in relation to the region's hydrologic and fire regimes. The model indicates the shifts in types of plant communities to be expected if the hydrologic and fire regime should change as a result of onsite management or offsite activities that affect a site. The rates of change are the minimum time required for a transition to a later successional stage. The plant communities and their environmental characteristics are described in Table 1.

above the ground surface. Plant communities exist along continuous hydrologic gradients, so the exact boundaries along these gradients in the successional model are somewhat arbitrary. However, these boundaries do suggest what type of shifts (from wetter to drier community types, or vice versa) we can anticipate as a result of specific long-term changes in a site's hydrologic regime.

The fire regimes of the communities in the successional model were defined in terms of the interval between moderate intensity, growing-season fires that would allow each of these communities to continue to exist over long periods of time (Figure 1). The fire interval ranged from frequently burned early successional, herbaceous or open canopy pine flatwoods communities, through long fire interval, late successional forest communities. If the interval between fires is long enough, we would expect each community to shift to a later successional stage as indicated in the model. Alternately, if the fire interval were shorter for a sufficiently long period of time, we would expect each community to gradually shift to an earlier successional stage.

Some of the communities are significantly influenced by other environmental factors not illustrated in Figure 1. The presence of limestone bedrock at or near the ground surface and the depth of organic soils, which is itself strongly influenced by site hydrology, have major influences in determining the structure and taxonomic composition of many South Florida community types (Duever *et al.* 1986). Flowing water in streams and its associated pattern of rapidly rising and falling water levels following rainfall events on the upstream watershed produces a very different hydrologic regime from that found in most South Florida communities where surface and groundwater levels rise and fall much more slowly as a function of seasonal rainfall and overland flow patterns (Ewel 1990). Salinity of ground and surface waters is a major determinant of plant community composition in coastal environments (Davis 1943, Craighead 1971). The moderating effects of permanent surface water on winter cold front temperatures in coastal environments allow both wetland and upland tropical vegetation to colonize and survive there (Duever *et al.* 1994, McVoy *et al.* 2007).

Transitional Models

We developed two transitional models for South Florida, one for communities occurring on organic soils (Figure 2), and another for those occurring on mineral soils (Figure 3). In these models, we again depicted the communities as seral stages moving from a very fire-tolerant early successional herbaceous or shrub community to a fire-sensitive late successional forest community as the fire interval increases.

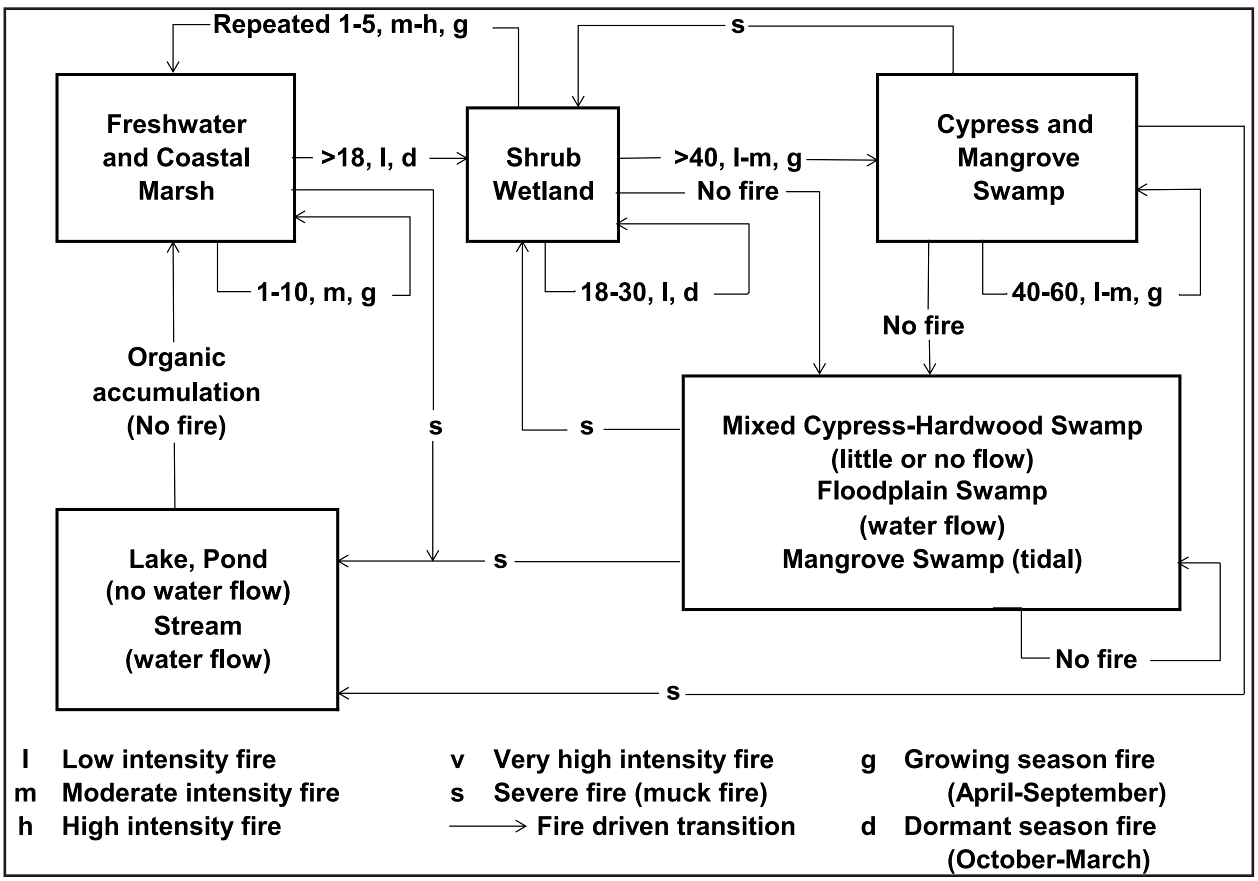

Figure 2. A conceptual fire transition model of major South Florida plant communities occurring on organic soils. The transitions include fire regimes that would maintain an existing community or that would be required to allow it to shift to an earlier or later successional stage. The plant communities and their environmental characteristics are described in Table 1.

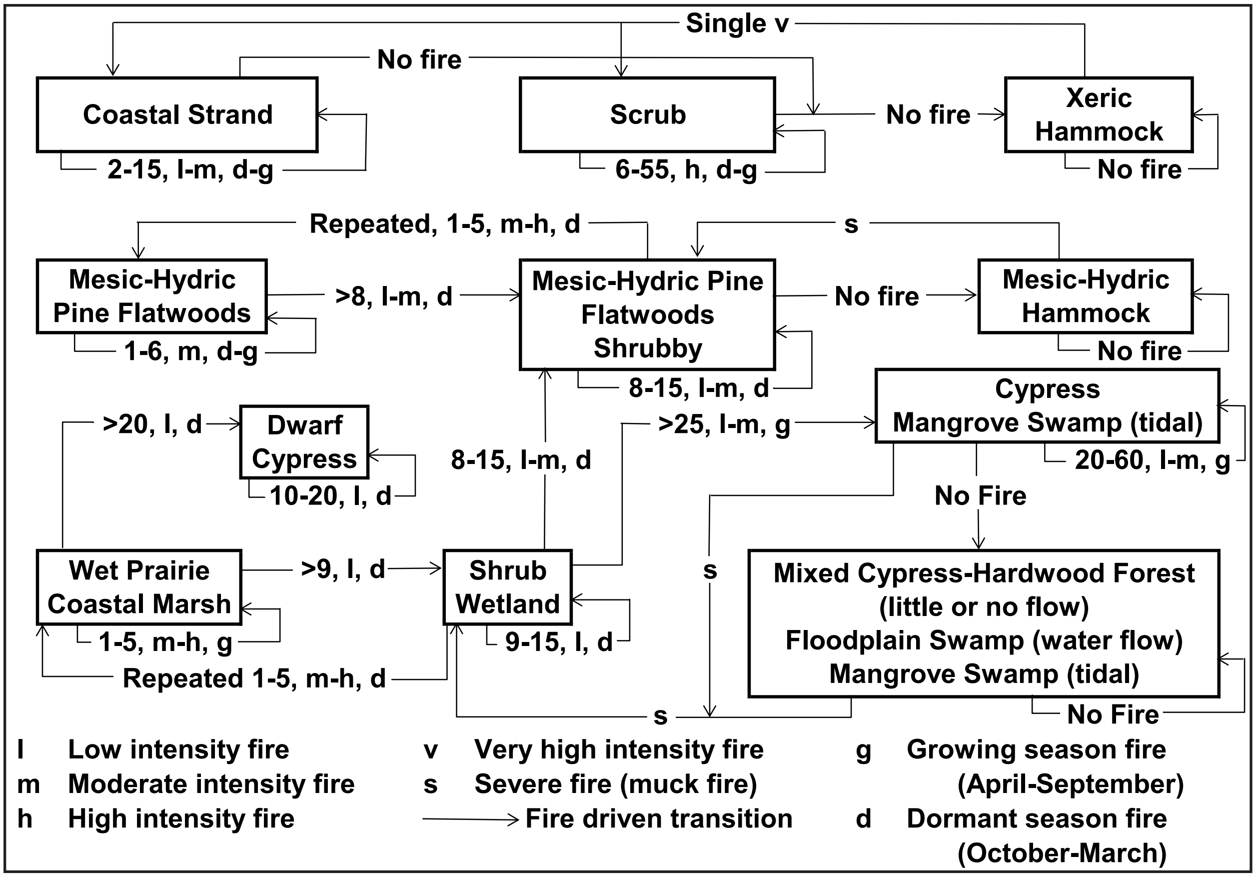

Figure 3. A conceptual fire transition model of major South Florida plant communities occurring on mineral soils. The transitions include fire regimes that would maintain an existing community or that would be required to allow it to shift to an earlier or later successional stage. The plant communities and their environmental characteristics are described in Table 1.

However, we have attempted to identify certain characteristics of the fire regime that would: 1) maintain a specific plant community, 2) allow the community to proceed to one or another later stage of succession, or 3) result in the conversion of the site to an earlier successional stage. The fire regime parameters were: 1) a range of fire intervals, 2) fire intensity, 3) whether the fire occurred during the vegetative growing or dormant season, and 4) occurrence of a single severe fire. Fire intensity was based on flame lengths expected to occur in a fire, which are largely a function of the fuels available and weather conditions during the fire. We have defined low intensity fires as having flame lengths of 1.22 m, moderate intensity fires of 1.22 m to 2.44 m, high intensity fires of 2.44 m to 3.35 m, and very high intensity fires as having flame lengths over 3.35 m (National Wildfire Coordinating Group 1993). A severe fire consumes a sufficient depth and area of organic soils to kill vegetation that would otherwise survive and resprout after even very high intensity surface fires. We defined the growing season as April through September and the dormant season as October through March (Robbins and Myers 1992).

DISCUSSION

The identification of the major South Florida plant community types was accomplished through a series of meetings designed to capture the knowledge and experience of a number of individuals who had been involved in the management and restoration of South Florida plant communities for many years. We started with conceptual models developed by similar methods for individual sites or large regions in southern and central Florida. We viewed this as a process for developing an initial synthesis that could be easily revised as additional information on the composition, structure, and characteristics of the major plant communities became available. It could also be modified to provide more or less detail as the geographic area being considered was scaled down or up, respectively.

The first step was to agree on a plant community classification that was explicitly related to hydrologic and fire regimes that would help South Florida land managers manage and, as necessary, restore their lands. Where there was insufficient data for South Florida plant communities, we either agreed to accept the transitions identified in the earlier models or to use our own best professional judgment to revise the transition values. As described in the methods, we did have some information on many of the transitions. However, we needed to be careful to identify unnatural conditions on sites disturbed by human activities where the environmental conditions might have changed, but the plant communities had not yet transitioned to the new conditions or where plant communities had been altered but one or more of the environmental conditions had not changed. We expect that in the future there could be numerous improvements to these models as more site-specific data become available and we learn from our management and restoration efforts. While improvements in the successional model could come fairly quickly and steadily over time, improvements in the transitional models are likely to take longer because of the long time periods involved in many of the transitions and the limited information of site fire histories.

Model Assumptions

One major assumption about the models is that seed sources are readily available to facilitate succession to the next seral stage or to return the site to an earlier seral stage. This is the main reason for saying the model illustrates maximum rates of successional change. There are numerous factors that affect the timing of the arrival of seeds at a particular site, some of which could significantly slow rates of succession. Seed production, germination, and seedling survival can be quite variable from one year to the next. Increasing distances from seed sources to potential colonization sites can result in increasingly lengthy delays in a species' colonization of available sites, particularly for those species without long-distance seed-dispersal mechanisms. The presence of perches on or near a site can be important for the arrival of seeds consumed and dispersed by birds.

The models assume a long-term perspective in that the plant communities are the result of processes that have been operating for decades, if not centuries. Therefore, it is important to recognize that plant communities in transition from relatively recent changes in the processes affecting them, including management activities, will likely vary in their resemblance to the plant communities described in these models.

The length of time over which the transitions occur can vary substantially. One example is associated with changes in the hydrologic regime of herbaceous wetlands. If hydrologic conditions in a wet prairie shift to the longer hydroperiods more representative of a marsh, the change in the plant community will be very slow because of its dependence on the accumulation of an organic soil, which can take centuries to develop. The opposite transition from a marsh to a wet prairie can occur much more quickly, since the organic soil in a marsh can be lost to oxidation or fire in a decade or less under an appropriately drier hydrologic regime.

Another example is associated with a change in fire frequency. Once a later seral stage has become established on a site, most of the associated species will readily resprout following a fire that would have eliminated them when they were seedlings or young individuals. Thus, elimination of these species, allowing the site to return to an earlier seral stage, often requires more frequent and severe fires than will be necessary to maintain this earlier seral stage after it has reestablished.

Application of the Models

The models are generalizations about our current understanding of the environmental factors that determine the characteristics and distribution of the major plant communities present in South Florida. It is important to realize that, while we believe that these models represent our best understanding about how these types of systems operate, we are aware of sites that are clearly exceptions to any of our generalizations. One exception would be a community that is simply a natural variation of one of our generalized plant communities, which exists in a unique environmental or historical setting. Another more obvious influence would be sites affected by human disturbances that have influenced their community structure and composition.

While there are many ecological influences on the South Florida ecosystem that are not incorporated into these models, we feel that the models can be quite useful because their level of detail is the level at which we manage and work to restore and protect these systems. This is the level at which a site is affected when we conduct a prescribed burn or when we restore the hydrology of a drained wetland. It is also the level at which they can be impacted by many types of offsite development, particularly those associated with hydrologic alterations or the kinds of development that affect our ability to apply prescribed fire.

While the models discussed in this paper have been developed specifically for South Florida, they are based on at least five similar models previously developed for southern and central Florida land managers on a variety of landscapes ranging in size from 4000 ha to 300 000 ha. Progress in the development of subsequent models has relied heavily on experience with one or more of the earlier models. The earlier models not only provided a framework for initial drafts of at least portions of the new model, but in many cases provided information that could be used in development of the plant community classification and characterization as well as some of the quantitative estimates we needed for defining the transitions. At this point in time, these models represent our current set of hypotheses about South Florida plant communities and how they operate in a naturally functioning environment.

ACKNOWLEDGMENTS

We would like to thank the members of the South Florida Interagency Fire Management Council who participated in the development of the South Florida plant community classification and succession and transition models, in particular D. Black, J. Haner, and S. Smith. Appreciation is also extended to J. McCollom for preparation of graphics, and L. Roberts, J. McCollom, and E. Cowan for reviewing and commenting on the final draft of the manuscript.

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